Analog Electronic Circuits
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Lecture - 38
Precision High-Swing Cascode

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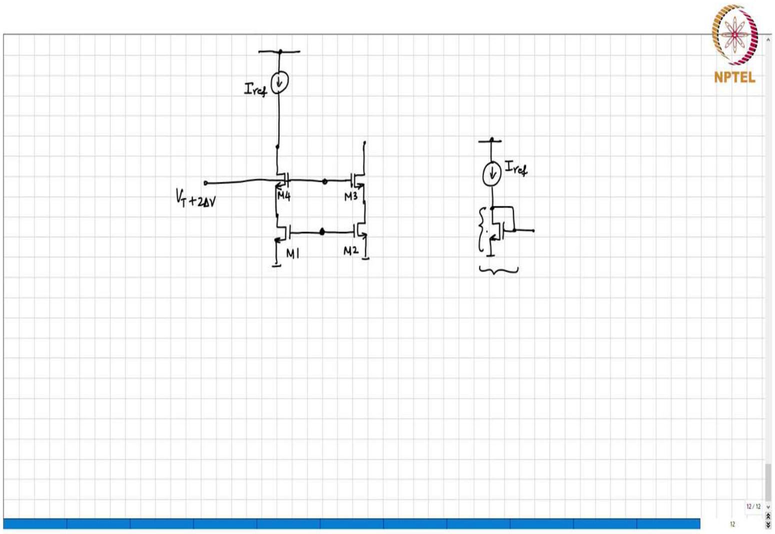

Alright, but what is the difference I mean? So, one answer to that question is the following, is to just do this, right. We have seen this before in the context of biasing and current mirrors, right. So, how was this working? Well, we are applying a I mean how did we come up with this circuit? We are applying the voltage to the gate measuring the?

Student: Current in the drain.

Current in the drain and comparing it with I_{ref} and then going in and you know varying the gate voltage. So, that the current is exactly equal i, is this clear? Ok, now why cannot we just simply do the same thing? Here as you can see, if the g_mR_o the transistors are infinite, in other words the output impedance of the transistor was infinite, then I mean that regardless of what the drain potential of the transistor is, you will always get the same answer for the gate. I do not know if anyone makes sense. I see completely blank faces, ok. Let me explain that all over, alright.

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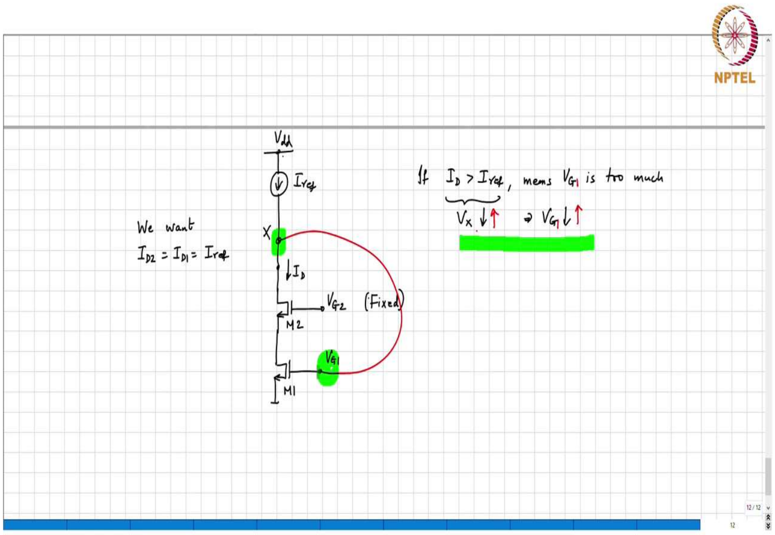

So, let us call this voltage and V_G, ok. And let us call this M2 and 1. This is, V_{G2}, V_{G1}, alright. Ok, now let us say I want the current in M2 and M1 to be exactly equal to I_{ref}, right. So, V_{G2} is a fixed voltage, we have no way of varying it, alright. The question I am asking you is, how will we choose V_{G1} or how will we find V_{G1} so that the current in M1 and M2 is exactly equal to I_{ref}. What will we do?

What will we do? In principle what will we do? We want I_{D2} which is equal to I_{D1} to be equal to I_{ref}. So, what will we do? In principle what will we do?

Student: We will vary the gate voltage.

We will vary the gate voltage, V_{G1}.

Student: And measure.

Measure the current in the drain.

Right, using an ammeter and then go and tweak V_{G1} in the right direction, correct? Alright. So, basically and you know we have seen this over and over again before. So, how will we do this? How will we implement this in practice?

So, you compare the drain current with.

Student: I_{ref}.

I_{ref}, this is V_{dd}, alright. And what comment can you make about this node X?

Student: I_D.

If I_D is greater than I_{ref}, means?

If I_D is greater than I_{ref}, that basically is equivalent to saying V_X is going.

Student: Down.

Down, what does it mean?

Student: V_G is too much.

It means V_G is too much and therefore V_G must reduce ok, and vice versa. It is exactly like the basic diode connected transistor, except that in the diode connected transistor, the drain potential was exactly the same as the gate potential. Here what is the drain potential? We will come back to that, ok. So, if V_X goes up, Vg must go up, V_{G1} must go up and if V_X goes down, V_{G1} must go down, correct? So, how will it be, what can we do? What can we do?

Student: V_{G1}.

Ok. So, one idea is to say, why do not I just connect X to V_{G1}. What is the problem with this?

Student: higher than the potential of the drain. So, drain of M.

Yeah, so, basically since V_{G2} is not known a priori, right, ok, by simply connecting the source, the node X to V_{G1}, which definitely ensures negative feedback, right? M2 will not be in the.

Student: Saturation.

Saturation region, right? Ok, alright. So, what can we do to fix this problem? In other words, when V_X goes up, V_{G1} must go up, however.

Student: M2 should be in saturation.

M2 should be in saturation, which basically means that, I mean, and why is M2 not in saturation because the potential of node X is too low. So, what do you think we can do between V_{G1} and V_X, which ensures that when X goes up, V_{G1} also goes up, but X is at a much larger potential than V_{G1}?

Student: less than 1.

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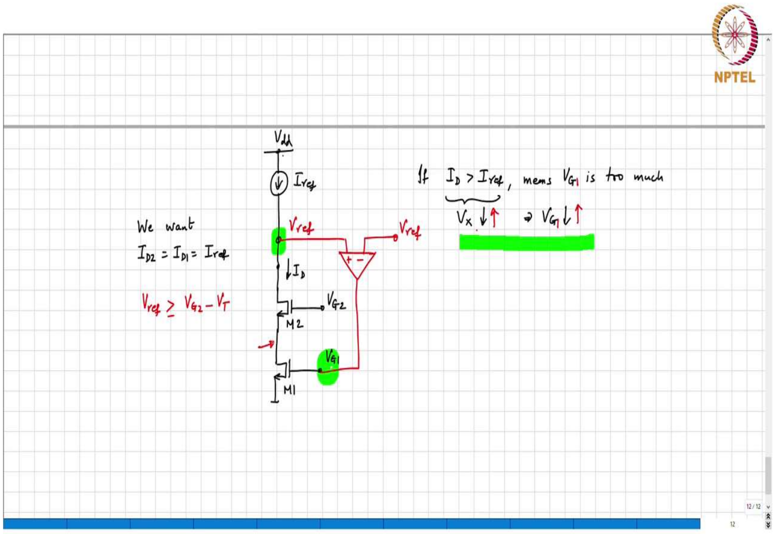

In principle you cannot put a voltage divider because it will, alright, ok. And so, therefore, and what is the drain potential of, what is the potential as a drain of V_{G1}? Yes, Roy, I like Roy because he always gives me the wrong answer. What is the source of M2?

Or the drain of M1?

Come on.

I am a hungry man. I hope you are too.

All your friends are going to beat you up after the class now, if you go and give me wrong answers. Yes.

Student: V_{ref} - V. V_{ref} - V.

Where is V_{ref}, man?

Student: V_{G1} - V_T.

V_{G1} - V_T.

Student: V_{G1} - V_T.

There is V_{G1}, V_{G2}, V_{ref}, V_T, ΔV, you make all possible combinations and tell me, you know, until we have blue in the face. Can somebody tell me the correct answer. So, can we go for lunch?

Student: Yes, sir. Yes, sir.

And India got in between independence on 15th August and you know, Republic days, January 26th and sun rises in the east. All this is correct. Can you please tell me what the drain potential of M1 is?

Student: V_{G2} - V_T.

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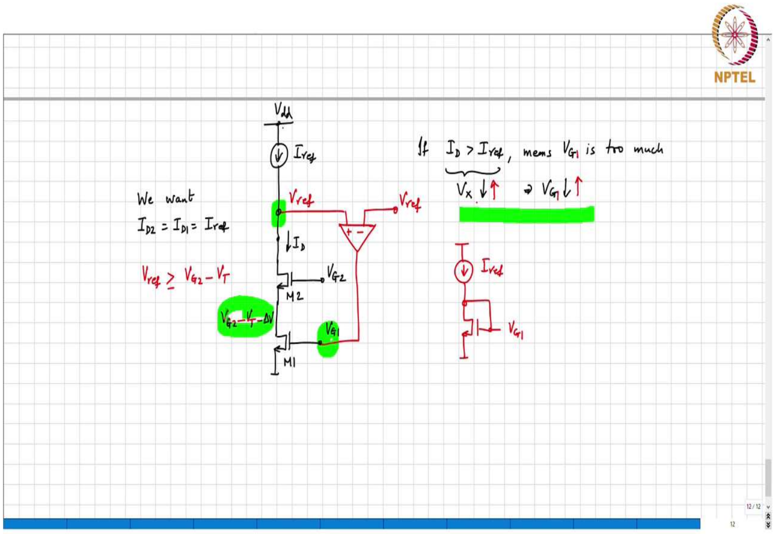

Ok. So, basically this is nothing but V_{G2} -V_T.

Student: Under root.

Yeah, whatever, under root all that stuff is Δ?

So, so basically what is this? What is this complicated arrangement basically giving us? It is telling, it is answering the question. Ok. What gate voltage must I apply to the transistor M1. So, does its drain current equal?

Student: I_{ref}.

I_{ref} when its drain voltage is V_{G2} -V_T - Δ, ok. So, this you can see is one order of magnitude, I mean it is an order of sophistication more than simply connecting the drain, the gate and the drain together, right where? If we had this, ok. What is this answering the question to, I mean what is this negative feedback, what loop, what question is it answering? What should be this V_{G1}? So, that the transistor carries a drain current I_{ref} when the drain and the. So, the gates are at the same potential, alright.

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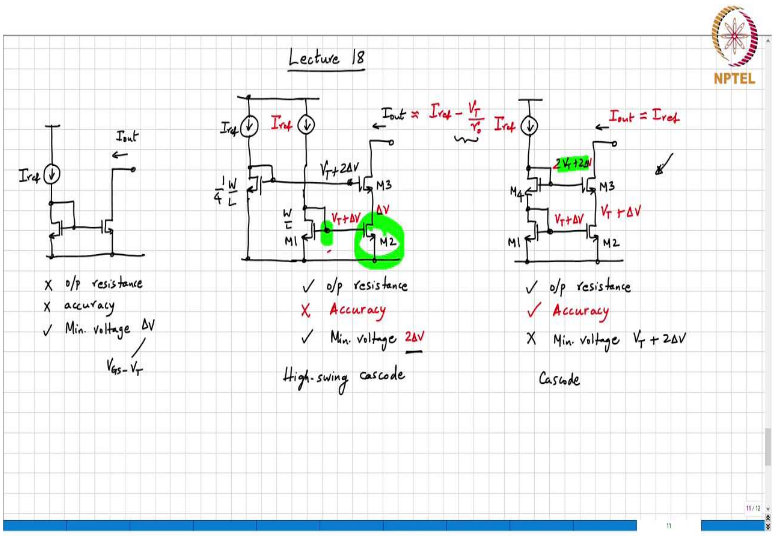

And that is why these things were not working well. This, now if you go and take that answer and apply it to M2 whose drain potential is different. Obviously, they are going to get an error, right? So, what are we doing here now? Here we are answering the question, what gate voltage must I apply to M1. So, does its drain current equal?

Student: I_{ref}.

I_{ref} when its drain potential is V_{G2} - V_T - Δ, ok, alright. And because V_{G2} is something that we can choose, let us quickly finish off, ok. Now, if I want to make a cascoded current mirror where there is no error and the output resistance is high, now tell me what I should do? I want to generate a current I_{ref} now. What will I do?

Student: We need another.

Ok, we need another?

Student: Current source.

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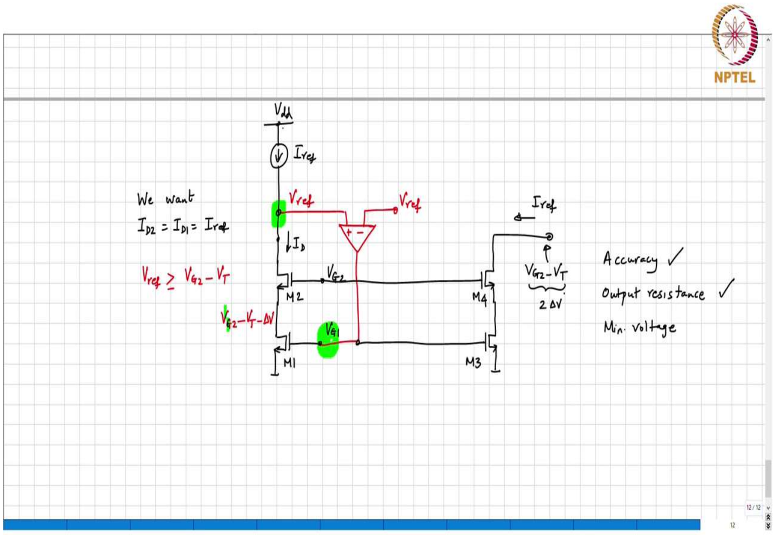

Ok, connect this to the gate of another transistor, ok which is identical in size, ok then with another transistor with a gate potential, V_{G2}, ok. And this is going to give me?

Student: I_{ref}.

I_{ref}, no matter what that V_{G2} is, you understand why? I mean you do not need to know anything to figure this out, right, alright. As long as M2 is in saturation, right. It does not matter to first order what V_{G2} is because M3 is identical to M1, M4 is identical to M2. So, M3 has, M3 and M1 have the same gate source potential, they also have the same drain source voltage. So, the current in M4 is going to be and in M3 is going to be exactly the same as that in M1, is that clear? Ok, alright. So, now, what should V_{G2} be chosen? So, now what can we, what claim can we make about accuracy?

Alright, what about output resistance? It is good or bad.

Student: Good.

It is $g_m R_o^2$, alright, what about headroom? That depends on the choice of V_{G2}. So, what is the minimum voltage that is needed for this current source to work like a current source? It depends on V_{G2}, I just said that just now, if you know V_{G2} - V, alright. So, if you want to make that the smallest possible which is 2 ΔV, what comment can you make about what should V_{G2} be therefore?

Student: 2 ΔV.

So, we want this to be 2 ΔV. So, therefore V_{G2} must be V_T + 2 ΔV. So, how do we get V_T plus, we have already seen that. So, what do we do?

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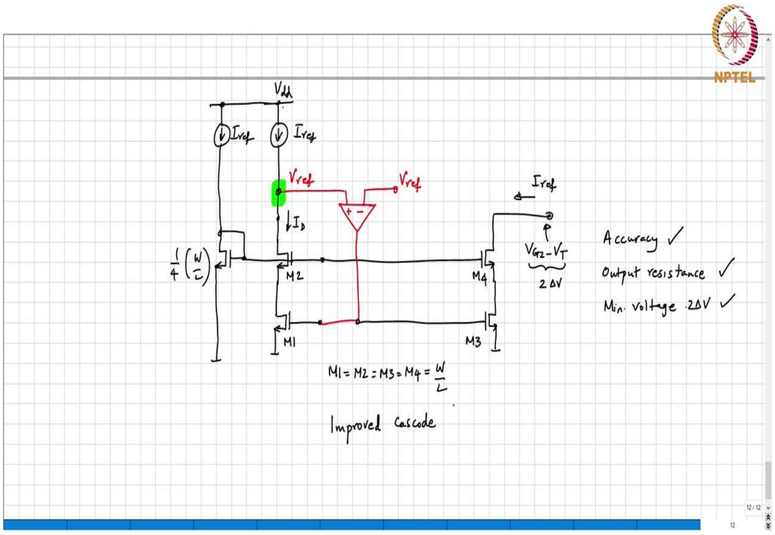

We somehow get another I_{ref} and go through a transistor which is one fourth the size and connected there. So, this is W by one fourth W/L, whereas, all these guys M1, M2, M3, M4 is W/L, ok. So, this not only gives you a minimum voltage of 2 ΔV it gives you an output resistance of $g_mR_o^2$ as well as a very accurate replica of the current I_{ref}, does it make sense? And as you can see the circuit is, you know I mean the complexity of the circuit is considerably higher, right. And I mean you know it basically comes down to saying that this is the high swing cascode, this is the; this is the normal cascode, ok.

And this is the improved cascode, alright. And as you can see, I mean it is basically not, I mean somebody did not wake up by a dream of something and you know add four more random transistors, right, there is a reason why?

I mean there is a reason why, I mean it is not for nothing that people say necessity is the mother of invention, right. See with this was invented the course you know to get high output resistance and then somebody recognize that you know well there is an accuracy problem, there is a swing problem, right. Especially, when supply voltage is shrunk from, you know 5 volts, 10 volts in the olden days.

But since we know how these circuits come about, they are a lot simpler than they see, you understand, right? And which is why I keep yelling and screaming, saying you need to know the basic building blocks like the back of your hand, right?

If every time you see a common gate amplifier, you are again scratching your head and saying, "Oh, let me go and draw the right KCL and KVL and figure out what you know this thing is and what that thing is," you know that when you now put multiple blocks together, it will all start looking very, very complicated, right?

But the fact that we know all the building blocks and we know how they came about means that when you see more complicated circuits, you should be able to correlate them to something. I mean, basically break them apart into simpler blocks, which you know work. And therefore, you should be able to understand a more complicated circuit.

And you should also be able to understand, you know, why I mean, for example, here you know there are. So many devices are here for a reason, ok? It is not for, it is not, you know, as I said, somebody did not wake up and basically say, "Let me add four more transistors and, you know, let me see if the world becomes a better place." Alright, ok.